Soil Fertility and Farming Systems in a Slash and Burn Cultivation Area of Northern Laos(<Special Issue>Sustainable Agro-resources Management in the Mountainous Region of Mainland Southeast Asia)

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Abstract

The physico-chemical properties of the soil in shifting cultivation fields in Xiang Ngeun district, Luang Phabang province were investigated in order to provide a basis for developing an agricultural system that will be sustainable under higher population pressure on the land and increased demand to engage in intensive farming. The soils in the study area have reasonably high contents of soil nutrients despite being on erosion-prone sloping land. Soil fertility status may not be fully restored even when the length of fallow is 10 years. The nutrients accumulated in the soil during fallow period are small compared with the nutrients supplied from the ash input when the biomass is burned so that soil nutrients were found not to be exhausted after a single year of cultivation. However, the density of weeds increases as the fallow period is shortened. Therefore, fallow plays an important role in weed control during the cropping period. These findings suggest that an agroforestry system that combines crop cultivation with paper mulberry production could be a sustainable farming system for short-fallow shifting cultivation. To be acceptable to the farmers, this agroforestry system must be effective both in controlling weeds and in generating income for the shifting cultivators.

Keywords: agroforestry system, fallow management, Northern Laos, paper mulberry, slash and burn cultivation, soil erosion, soil fertility, weed control

I Introduction

Slash-and-burn farming (also called shifting cultivation or swidden agriculture) is a major land-use practice in the hilly areas of Laos [Fujisaka 1991; Lao PDR, State Statistical Center 1990]. Most of the forests within these areas have already experienced slash-and-burn prac-

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tices several times. Roder *et al.* [1994] reported that the combined effects of increased population density and government policies limiting access to land have reduced fallow periods from about 40 years in 1950 to only 5 years in 1992. The Government of Laos aims to reduce and stabilize slash-and-burn cultivation through a gradual expansion of other production systems such as permanent cash crop production, and wood and fruit production. The forest law of 1996 states that an individual family is to be allocated an area of no more than three hectares. In addition, the clearing of new plots in well-developed natural forest or fallow forest is also prohibited. This forces farmers to do more intensive farming on existing fields.

Although there have already been several studies of slash-and-burn farming in Laos [e.g. Nabong Technical Meeting 1994], the sustainability of intensive farming systems is not clear, partly because little information on soils in Laos is available at this stage. Therefore, in the research reported here, we investigated soil physico-chemical properties in shifting cultivation fields to provide a basis for developing a practical and sustainable agricultural system. We also propose a model system for sustainable intensification of farming systems in this region.

II Description of the Study Area

The study area is situated in Nam Khan Watershed in Xiang Ngeun district, Luang Phabang province about 25 km southeast of Luang Phabang city. The Nam Khan River runs through

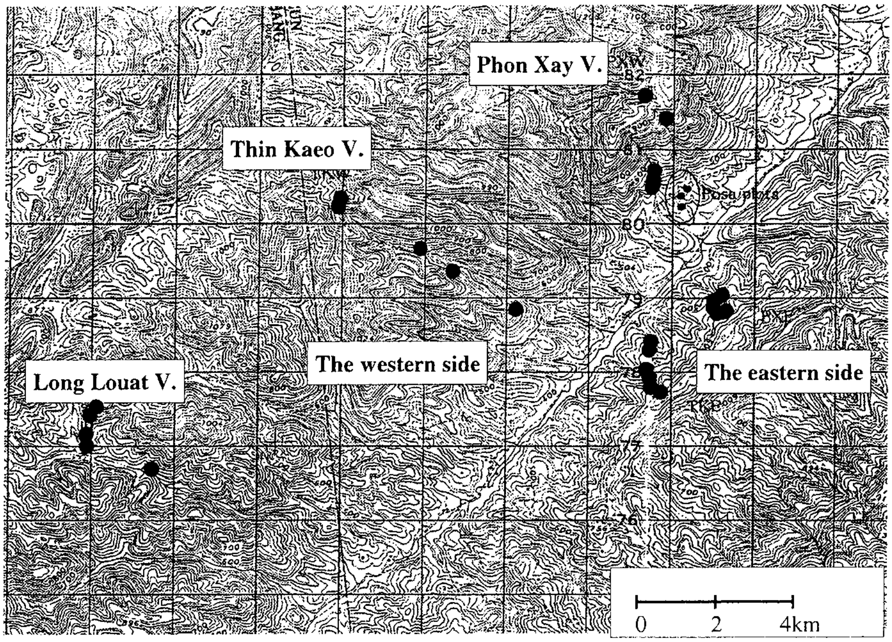

Fig. 1 Map of the Study Area in Xiang Ngeun District, Luang Phabang Province, Lao PDR

Table 1 General Information of the Villages Studied

Village Name	Thin Kaeo	Phon Xai	Long Lonat
Year of establishment	Old village	1972	1991
Population (household)	900 (145)	634 (102)	229 (40)
Lao Loum	5 (1)	112 (21)	14 (2)
Lao Thung	645 (110)	552 (81)	184 (35)
Lao Soung	240 (34)	0 (0)	31 (3)
Total area (ha)	1,484	1,300	3,300
Agricultural land (ha)			58.9
Swidden field	123	103 (fallow 120)	30.1(only rice field)
Paddy field	15.5	17.7	3
dry season	no data	12.8	3
upland field	2.7	51.3	23.3
Farming style (household)			
Only shifting cultivation	119	75	32
Only paddy field	5	6	1
Paddy + Swidden field	20	21	4
Paddy field dry season	23	22	5

the district from southwest to northeast. Its total watershed area is 170.8 km^2. The mean air temperature is 26.2˚C, and the annual precipitation and number of rainy days were 1,050 mm and 103 days in 1998, and 1,226 mm and 122 days in 1999, respectively. Precipitation occurs mostly from May to October.

Thin Kaeo village (TK), Phon Xay village (PX) and Long Louat village (LL) were selected for the present study (Fig. 1). General information from these three villages obtained in interviews with the village headmen is summarized in Table 1. Land-forest allocation to households was implemented in 1996, 1998, and 1997, in TK, PX, and LL, respectively. TK village is an old village. PX and LL had been resettled in 1972 and 1991, respectively. Residents are mostly Lao Thung people who engage in slash-and-burn cultivation. The percentage of the households engaged in slash-and-burn cultivation is 82 percent in TK, 73 percent in PX and 80 percent in LL. Total area of LL is very large because it includes the territory of the previous settlement, although LL villagers hardly use this land as it is very far from the present settlement.

The average cropped area each year including upland rice per household is about one ha. On average there are six people and two laborers in a household. The land-forest allocation gave each household from one to four plots with a total field area of one to five ha according to the number of laborers in a household. Households that possessed paddy fields received only one upland field plot so they must cultivate the same plot every year.

According to the TK village headman, yields of upland rice had become lower than before so that many villagers grew Job's tears instead of upland rice in 1999. However, the price of Job's tears declined sharply in 2000. The percentage of households suffering from a rice shortage will probably amount to about 70 percent in 2000, up from 40 percent in 1999. The village headman of PX said that it was difficult for them to plant lowland rice in the dry season because the amount of water in the tributary has decreased in the past five years. He thought that this was because of a decrease in forest area caused by slash-and-burn cultivation, although he had no empirical basis for this belief.

He believes that they have to reallocate land among villagers in order to protect forestland. Chikami and Komoto [1999] reported that traditional institutions of forest management are weak in newly established villages in central Laos, which may cause degradation of forest. We believe that this is not the case in the villages of our study because these communities all have rather long histories even before the re-settlement. Instead, interviews with villagers revealed that they understood the need for proper land-forest allocation in order to accomplish sound forest management. Problems regarding the shortage of cultivable land, degradation of soil, and decrease in crop yields have arisen after the implementation of land-forest allocation in 1996.

III　Methods for Evaluation of Soil Fertility

III–1　*Soil Sampling*

Based on interviews with farmers on land use history, we selected 27 soil-sampling sites (10 in PX, 12 in TK and 5 in LL) in plots with different land use histories (Fig. 1). The land use history of the sampling sites is summarized in Table 2. Site name stands for the year of last fallow or cultivation in 1999. Four sites are in natural forest, 4 sites in long fallow fields more than 10 years, 9 sites in short fallow fields less than 10 years, and 10 sites in currently cultivated fields. Most of the sites had been under fallow for from 4 to 6 years before cultivation, but TKW-C1 was fallow for more than 10 years before cultivation, and TKE-C1 was fallow for 2 years before cultivation. The slope gradient of most sites ranged from 10˚ to 30˚ and their elevation ranged from 600 m to 1,100 m above mean sea level. Soil samples were collected from the surface 0–5 cm layer and the subsurface 20–25 cm layer. Soil sampling was carried out three times: before burning (February), after planting (July) and after harvest (October) in 2000. Five samples were collected from every layer and mixed into one composite sample. Two or three undisturbed soil samples were also collected by a 100 ml core sampler and used for water permeability analysis.

The soil profile was described at five sites: TKE-Fa20 (the eastern side of Nam Khan River, the 20-year fallow forest in TK village), PXE-C1 (the 1-year cultivated field in PX), PXW-NF (the western side of the river, the natural forest in PX), LLW-Fa26 (the 26-year fallow forest in LL village), and TKW-C3 (the 3-year cultivated field in TK village). Soil samples were collected at depths of 0, 5, 10, 20, 40, 60 and 80 cm. This survey was carried out in February and October 2000.

III–2　*Analytical Methods*

Analytical items of soil property included pH, electrical conductivity (EC), exchangeable cations (Ca, Mg, K and Na), cation exchangeable capacity (CEC), total carbon (T-C), total nitrogen (T-N) and available phosphorus (AvP). We added particle size distribution, sesquioxides content (Al, Fe and Si), clay mineral composition, point of zero salt effect (PZSE) and σp for the samples collected from the soil profiles.

Soil pH was measured under the condition that soil to water ratio is 5 g to 25 ml. EC was measured before pH measurement. Exchangeable cations (Ca, Mg, K and Na) were extracted with 1 M-ammonium acetate (pH 7.0) under the condition that soil to solution ratio is

Table 2 Sample Name, Slope Direction and Gradient, and Land Use History

Sample Name		Slope Direction and Gradient	Land Use History Year										
			90	91	92	93	94	95	96	97	98	99	2K
PXE	NF	N70° W, 35°											
	Fa5	S80° E, 18°				R	R						
	Fa2	S80° E, 17°							R	R			
	C1	S80° E, 21°					R					R	
	C3	N40° E, 24°			R					R	R	J	
PXW	NF	S30° W, 30°											
	Fa15	S50° E, 26°											
	Fa3	S80° E, 25°							R				
	C1	N30° E, 32°			R							R	
	C4	E, 33°							R	R	J	J	
TKE	Fa20	N20° W, 13°											
	Fa8	N20° W, 34°		R									
	Fa4	N40° W, 28°					R	R					
	Fa2	N45° W, 15°							R	R			
	C1	N45° W, 13°						R	R			R	
	C3	N80° W, 13°		R	R					R	R	J	
TKW	NF	S20° E, 19°											
	Fa30	S34° W, 23°											R
	Fa6	S11° E, 18°				R							R
	C1	S34° W, 23°										R	R
	C2	N61° E, 36°	R	R							R	R	
	C3	N16° E, 32°	R							R	R	J	
LLW	NF	N10° E, 11°											
	Fa26	S75° W, 11°											R
	Fa6	S40° W, 20°				R							R
	Fa2	S30° E, 5°				R					R		
	C2	S75° E, 17°		R							R	R	R

Notes: PXE, the eastern side of the river in Phon Xay village; PXW, the western side of the river in Phon Xay village; NF, natural forest; Fa, fallow field; C, cultivated field.
The figure after letter represents fallow or cultivated period (yr).
R, upland rice; J, Job's tears; fallow

5 g to 25 ml by reciprocal shaking followed by centrifugation. The amounts of Ca, Mg and K were determined by atomic adsorption spectrophotometry, and that of Na by flame photometry (Shimadzu, AA-610S). Then, the residue was once washed with deionized water and twice with 990 g l^{-1} CH_3CH_2OH to remove the excess salt. The adsorbed ammonium was exchanged twice with 100 g l^{-1}-NaCl solution through reciprocal shaking for 1 hour followed by centrifugation for 10 minutes at 179 G. The ammonium ion content in the supernatant was determined by the titration method after Kjeldahl distillation and taken as CEC. T-C and T-N were determined by the dry combustion method with NC-Analyzer (Sumitomo, Sumigraph NC-80). AvP was extracted with an extracting solution containing 0.03 M NH_4F and 0.1 M HCl, followed by reciprocal shaking for 1 minute under the condition that soil to solution ratio is 1 to 20 (Bray-II method), and colorimetrically analyzed for Av-P using a spectrophotometer at 710 nm.

Particle size distribution for silt and clay fractions was determined by the pipette sampling method after wet decomposition of organic matter with 60 g l^{-1} of hydrogen peroxide and dispersion with the addition of 1 M NaOH to raise the solution pH to 9.5. Particle size distribution for fine sand and coarse sand fractions was determined by sieving. Al, Fe and Si oxides were extracted twice with an acid ammonium oxalate solution (0.2 M, pH 3.0) by reciprocal shaking in the dark for 1 hour [Mckeague and Day 1966], under the condition that soil to solution ratio is 1 to 25. They were extracted twice with a citrate-bicarbonate mixed solution buffered at pH 7.3 with the addition of sodium dithionite for 15 minutes at 75 to 80 degree centigrade [Mehra and Jackson 1960], using soil to solution ratio of 1 to 100. Al, Fe and Si contents in the extract were designated as Alo, Feo and Sio for the former extractant, and Ald, Fed and Sid for the latter, respectively. The contents of all the cations were determined using a sequential plasma spectrometer (Shimazu, ICPS-1000IV). Clay minerals were identified by the X-ray diffraction method (Shimazu, XD-D1w). The specimens of K- and Mg-saturated clay with parallel orientation were prepared by the alternate saturation technique using acetate and chloride salts [Jackson 1969]. X-ray diffractogram was taken for the air-dried K-saturated clay, then for the clay heated to 100, 350, 550 degree centigrade for 2 hours successively as well as for the air-dried Mg-saturated clay and for the clay treated with 10 percent glycerol. PZSE (designated as ZPC in their paper) and σp value (residual charge at PZSE) were determined by the modified salt titration (STPT) method [Sakurai *et al*. 1988].

IV　Results and Discussion

IV–1　*Morphological Properties*

The morphological properties of five soil pits for profile description are given in Table 3. Topographically, PXW-NF, LLW-Fa26 and PXE-C1 are located in the upper part of the hills, TKW-C3 in the middle part of the hills, and TKE-Fa20 in the middle part of the high terrace.

The parent materials are limestone and shale.

We could observe several differences between the western and eastern sides of the Nam Khan River. The western side has steeper slopes with more gravel in the very shallow soil layer, while the western side has the A and C profiles, except TKW-C3 which has a thin Bt layer. TKE-Fa20, on the eastern side, has the A, Bt and C profiles. The western side does not show a developed soil structure unlike the eastern side. These differences reflect the differences in topography and are not caused by the effect of burning. The profiles are classified as Inceptisols (PXW-NF and LLW-Fa26) and Alfisols (TKW-C3) on the western side and Ultisols (TKE-Fa20 and PXE-C1) on the eastern side [Soil Survey Staff 1987].

The soil texture is light clay to heavy clay. The surface layer has a medium organic matter content but it is very thin. According to Kyuma *et al*. [1985] after burning the color of soil profile was entirely different and Kadir *et al*. [2001] reported that soils at burnt areas showed a lighter A horizon than those of unburned areas. However, we could not observe differences in soil color between forest and cultivated lands. This may be because the accumulation of organic matter is weak during the fallow period.

IV–2 *Physico-chemical and Mineralogical Properties of Soil from the Pedons*

Table 4 shows sesquioxides content, charge characteristics and clay mineral composition of the soils in the profile description sites. There were no remarkable differences in sesquioxides content and charge characteristics between the western and eastern sides.

Fed value ranged between 20.0 to 45.0 g kg^{-1}. Higher values of crystalline oxides (Ald and Fed) indicate relative accumulation of oxidized Al and Fe associated with weathering. The activity ratios of Fe (Feo/Fed) and Al (Alo/Ald) become higher with the progress of weathering. Feo/Fed of the surface layer of LLW-Fa26, TKW-C3 and TKE-Fa20 are higher than 0.1, reflecting a rejuvenated condition by the addition of organic matter. PXW-NF and PXE-C1 showed lower Feo/Fed even at the surface layer, although Alo/Ald in PXW-NF were slightly higher than the other sites.

PZSE is mostly below four. According to Sakurai *et al*. [1989], PZSE shifted toward lower value by the presence of 2 :1 type clay minerals, organic matter and/or exchangeable Al. PZSE at the surface layer is generally low due to higher organic matter contents. The surface layer of PXW-NF and TKW-C3 showed higher PZSE value than the subsurface layers. This could be attributed to the presence of higher amorphous oxides (Alo and Feo) and exchangeable Ca and Mg (appendix) at the surface layer [*ibid*.; Sakurai *et al*. 1996]. σp is the remaining charge at PZSE, and both organic and mineral components capable of adsorbing H^+ or OH^- at PZSE contribute to the value of σp [Sakurai 1990]. σp is lower in a deeper horizon. σp of deeper layers at LLW-Fa26, TKE-Fa20 and PXE-C1 were below 1, and it ranged between 0.36 to 1.31 at TKE-Fa20. Therefore, σp is the lowest at TKE-Fa20 and the highest at PXW-NF and TKW-C3.

Illite, 2:1 type clay mineral, was the dominant clay mineral species across the sites. Kaolinite and quartz also showed higher contents. Hydroxy-interlayered vermiculite (HIV)

Table 3 Morphological Characteristics of the Soils Studied

Horizon		Depth (cm)	Color	Texture	Structure[a]	Boundary[b]	Consistence[c]	Rock fragment[d] (size cm)	Remark
PXW-NF	A	0–12	7.5YR3/2	LiC	w vf gr	cw	ss/p	m sbk st (1–2)	
	AC	–25	5YR4/3	LiC	1	gi	ss/p	a sbk st(2–3)	
	C1	–55	5YR4/4	LiC	1	gi	ss/p	a sbk st(2–3)	
	C2	–55+	5YR4/4	LiC	1		ss/p	d sbk st(10–15)	
LLW-Fa26	A	0–5	7.5YR4/2	Lic	w vf sbk	aw	ss/p		
	AC	–15	7.5YR5/4	LiC	w vf sbk	cw	s/p	c sbk sl(0.2–0.5)	
	C1	–20/25	7.5YR4/4	LiC	1	ci	s/p	m abk st(2–3)	
	C2(GL)	–45	7.5YR4/6	LiC	1	di	s/p	d sbk st(3), sl(0.5)	
	R	–45+	5YR4/6	LiC	1		s/p	d sbk st(5–10)	
TKW-C3	A	0–8	10YR3/3	LiC	m vf sbk	cw	s/p	f sbk sl(1)	
	Bt	–15	7.5YR4/3	HC	s f sbk	cs	s/vp	c sbk w(3)	clay cutan, chacol
	C1	–35	7.5YR5/6	HC	1	gw	s/vp	a abk w(3–7)	clay cutan
	C2	–80+	10YR5/6	HC	1		s/vp	d sbk st	clay cutan
TKE-Fa20	A	0–11	10YR3/3	LiC	w vf gr	cw	ss/p		
	Bt1	–36	7.5YR5/6	LiC	s c sbk	gi	ss/p	c sbk w(1–2)	many mottling, clay cutan, charcoal
	Bt2	–87	5YR5/8	HC	s c sbk	as	s/p	a sbk w(2–3)	clay cutan, chacoal
	C	–100+	2.5YR4/8	HC	1		ss/p	d sbk st stone	
PXE-C1	A	0–12	7.5YR3/2	HC	m f sbk	cs	s/vp	f sbk w(1)	
	AB	–25	7.5YR4/4	HC	m m sbk	cw	s/vp	f sbk w(2–3)	clay cutan, chacol
	Bt1	–50	7.5YR4/6	HC	w f sbk	gs	s/vp	c sbk w(5)	clay cutan, chacol
	Bt2	–100+	5YR4/6	HC	w f sbk		s/vp	c sbk w(5)	clay cutan

[a] Abbreviations used for soil structure. Grade: 1, structureless; w, weak; m, moderate; s, strong. Class: vf, very fine; f, fine; m, medium; c, coarse. Type: sbk, subangular blocky; gr, granular

[b] Abbreviations used for boundary. Distinctness: c, clear; g, gradual; a, abrupt; d, diffuse. Topography: s, smooth; w, wavy; i, irregular

[c] Abbreviations used for Consistence. Stickiness: ss, slightly sticky; s, sticky. Plasticity: p, plastic; vp, very plastic

[d] Abbreviations used for rock fragment. Abundance: c, common; m, many; a, abundant; d, dominant. Shape: sbk, subangular; abk, angular. Weathering: sl, slightly weathered; w, weathered; st, storongly weathered

Table 4 Sesquioxides Content, Charge Characteristics and Clay Mineral Composition of the Soils in the Pedons

Sample	Depth	Alo	Feo	Sio	Ald	Fed	Sid	Alo/Ald	Feo/Fed	σp	PZSE	Clay Mineral Composition				Soil Fraction		
	(cm)	———	———	——— (g kg^{-1})	———	———	———			cmol kg^{-1}		It	Kt	Qz	HIV	Clay	Silt %	Sand
The western side of the river																		
PXW-NF	0–5	1.13	1.94	0.16	2.22	34.17	2.80	0.51	0.06	4.77	5.34	++++	+	+	–	27.7	31.3	41.0
	5–10	1.21	2.05	0.13	2.37	33.37	2.18	0.51	0.06	3.94	5.86	+++	+	++	–	27.9	26.8	45.3
	10–15	1.18	1.86	0.10	2.36	36.12	1.76	0.50	0.05	3.87	4.84	+++	+	++	–	28.5	26.4	45.1
	20–25	1.15	1.68	0.08	2.70	45.05	1.99	0.43	0.04	3.99	3.38	+++	+	++	–	26.8	25.6	47.6
	40–45	1.01	1.56	0.08	2.59	35.98	1.80	0.39	0.04	4.06	1.12	++++	+	+	–	26.4	25.2	48.4
	60–65	0.95	1.59	0.08	2.31	36.44	1.58	0.41	0.04	4.04	1.11	+++	++	+	–	26.0	24.4	49.6
	80–85	0.91	1.52	0.09	2.48	38.78	2.05	0.37	0.04	4.00	1.27	++++	++	+	–	29.0	24.8	46.1
LLW-Fa26	0–5	1.38	4.07	0.13	3.01	19.98	1.84	0.46	0.20	3.66	3.33	++	++	+++	+	31.8	26.8	41.4
	5–10	1.25	3.10	0.07	3.18	22.03	0.91	0.39	0.14	3.93	1.28	++	++	++	+	39.0	28.8	32.2
	10–15	1.23	2.93	0.07	3.41	24.35	0.76	0.36	0.12	3.93	1.12	++	+	+++	+	38.9	28.9	32.2
	20–25	0.93	1.90	0.05	3.33	25.85	0.71	0.28	0.07	3.91	0.99	++	++	++	+	34.3	21.1	44.6
	40–45	1.08	1.09	0.09	4.14	33.91	0.80	0.26	0.03	4.05	0.56	+++	++	+	+	37.6	14.4	48.0
	60–65	0.94	0.79	0.09	3.66	30.09	0.82	0.26	0.03	4.11	0.43	++	++	+	+	32.8	15.4	51.8
	80–85	1.29	1.08	0.10	4.62	38.38	0.85	0.28	0.03	4.04	0.45	++	++	+	+	50.1	21.4	28.5
TKW-C3	0–5	0.82	4.13	0.39	2.43	32.08	2.20	0.34	0.13	3.47	10.55	++	++	+	+	40.2	36.6	23.2
	5–10	0.69	3.59	0.21	2.55	33.80	1.43	0.27	0.11	3.81	5.08	++	++	++	+	45.2	34.6	20.2
	20–25	0.61	2.42	0.11	2.55	34.69	1.18	0.24	0.07	4.09	2.74	++	++	++	+	48.0	35.3	16.7
	40–45	0.52	0.89	0.08	2.48	32.54	0.98	0.21	0.03	3.56	3.85	++	+	++	+	51.6	30.3	18.1
	60–65	0.54	0.91	0.08	2.57	35.25	0.99	0.21	0.03	3.51	3.77	++	++	++	+	52.2	30.9	16.9
	80–85	0.51	0.95	0.09	2.40	31.87	1.09	0.21	0.03	3.66	3.24	++	++	++	+	52.6	27.4	20.0
The eastern side of the river																		
TKE-Fa20	0–5	1.17	2.92	0.07	3.37	21.22	1.72	0.35	0.14	3.80	1.31	+++	++	+	–	41.6	40.6	17.8
	5–10	1.26	2.59	0.09	3.64	23.65	1.12	0.34	0.11	3.83	0.86	+++	++	+	–	43.2	40.2	16.6
	10–15	1.01	2.18	0.07	3.80	23.62	0.91	0.27	0.09	3.80	0.90	+++	++	+	–	44.5	39.7	15.8
	20–25	1.03	1.76	0.07	3.86	24.30	0.55	0.27	0.07	3.88	1.02	+++	++	++	–	49.7	36.4	13.9
	40–45	1.13	1.58	0.07	4.69	31.52	0.53	0.24	0.05	4.01	0.45	+++	++	++	–	57.4	30.9	11.7
	60–65	1.09	1.26	0.08	5.06	32.30	0.40	0.22	0.04	4.03	0.43	+++	++	+	–	60.2	28.4	11.4
	80–85	1.15	1.22	0.09	5.40	33.80	0.61	0.21	0.04	4.08	0.36	++	++	++	–	63.0	25.3	11.7
PXE-C1	0–5	1.45	1.79	0.10	3.78	25.54	1.53	0.38	0.07	3.68	4.48	+++	+++	–	–	47.2	33.2	19.6
	5–10	1.45	0.05	1.67	3.87	27.62	1.19	0.38	0.00	3.67	2.69	+++	+++	+	–	52.1	31.5	16.4
	20–25	1.47	2.16	0.08	4.42	30.77	0.96	0.33	0.07	4.05	1.21	+++	+++	+	–	55.0	30.1	14.9
	40–45	1.39	1.66	0.07	4.58	30.30	0.79	0.30	0.05	4.02	0.83	+++	+++	+	–	57.7	29.5	12.8
	60–65	1.21	1.57	0.07	4.47	31.56	0.75	0.27	0.05	4.04	0.83	+++	+++	+	–	58.9	25.1	16.0
	80–85	1.12	1.55	0.07	4.52	32.48	0.72	0.25	0.05	4.04	0.84	+++	+++	+	–	62.4	26.5	11.1

Notes: –, 0–5%; +, 5–20%; ++, 20–40%; +++, 40–60%; ++++, 60–80%

It, Illite; Kt, Kaolinite; Qz, Quartz; HIV, Hidroxy-interlayered vermiculite was found at LLW-Fa26 and TKW-C3. HIV is one of the highly erodible clay minerals, and soils containing HIV are not strongly weathered. The clay contents at PXW-NF decreased slightly with depth, but increased with depth at other sites. This indicates that erosion by rainwater quickly removed clay at the surface layer once the vegetation was cleared.

IV–3 *Relationship between Soil Chemical Properties and Land Use*

The soil chemical properties of pH, AvP, exchangeable Al, Ca, Mg, Na and K, CEC, T-C, and T-N at the depth of 0–5 cm and 20–25 cm were plotted against land use history in Fig. 2. Both layers showed a similar tendency, though those of the depth of 0–5 cm are slightly lower than that of the depth of 20–25 cm. Therefore, we will mainly discuss the data of the depth of 0–5 cm.

The values of pH were slightly higher on the western side than on the eastern side because of the input of limestone materials from the upper toposequence in the western side. The pH increases with an increase in fallow period within the first 10 years probably due to the accumulation of alkaline materials during fallow period and during cultivation periods due to the deposition of ash. The pH values, however, decreased after 10 years fallow, possibly because of the severe degradation of these fields before being abandoned. In other words, farmers did not utilize these plots for many years because the soil properties were too poor to cultivate continuously. This resulted in long fallow. Tanaka *et al.* [1997] reported that the soils under continuous cropping and fallow forest were more acidic than newly reclaimed soils of slash-and-burn cultivation. The experimental findings of Kyuma *et al.* [1985] showed higher pH value after 2 years cultivation than before cultivation. Our findings coincide with these observations.

Previous studies also described the decrease in exchangeable Al after burning [Tanaka *et al.* 1997; Kyuma *et al.* 1985; Tulaphitak *et al.* 1985]. However, the amount of exchangeable Al was high even at the cultivated field on the eastern side. The higher amount of Ca corresponds to the higher pH value. It is slightly higher on the western side due to the influence of the eroded materials from the limestone range. The values increased with the length of cultivation and fallow periods up to 10 years fallow. The distribution pattern of exchangeable Mg showed a similar trend with exchangeable Ca. Exchangeable K and Na, however, did not show any relationships with cultivation and fallow periods. The amount of exchangeable Na showed a slightly higher value in the eastern side than in the western side. According to Jordan [1987], Ca, Mg and K decreased rapidly after abandonment because soil erosion was accelerated. This observation does not coincide with our results probably because soil loss is not so serious in our sites due to the high clay contents. According to the technical report of Northern Agriculture and Forestry Research Center (personal communication), soil erosion loss in an upland rice field with 25–30 percent slope near the study area was annually 8.62 t ha^{-1}. This can be converted to 0.862 mm/year in thickness provided that the bulk density is 1.0 g cm^{-3}. High contents of exchangeable cations compared to strongly weathered soils elsewhere in the tropics are thought to result in low amount of soil erosion [Kyuma *et*

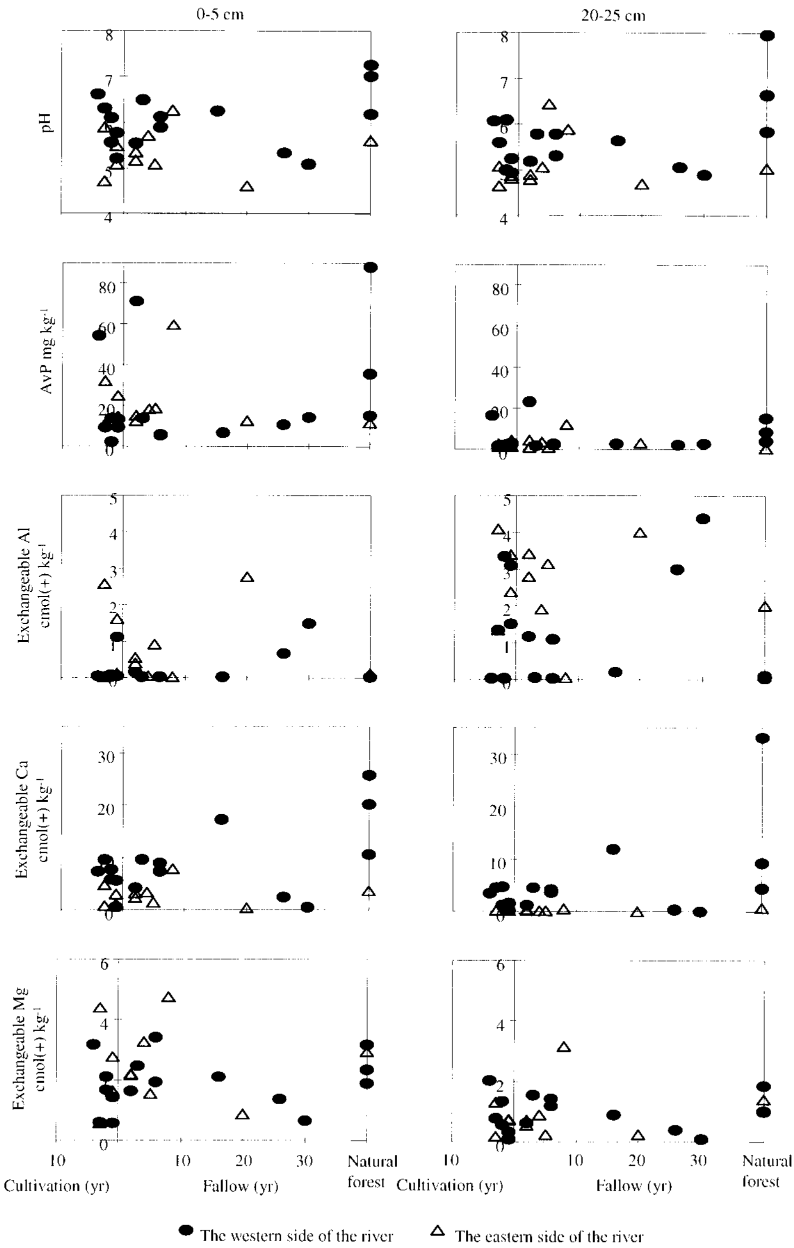

Fig. 2 Relationship between Fallow or Cultivation Period and the Chemical Properties of the Soils at the Depth of 0–5 cm and 20–25 cm in February 2000

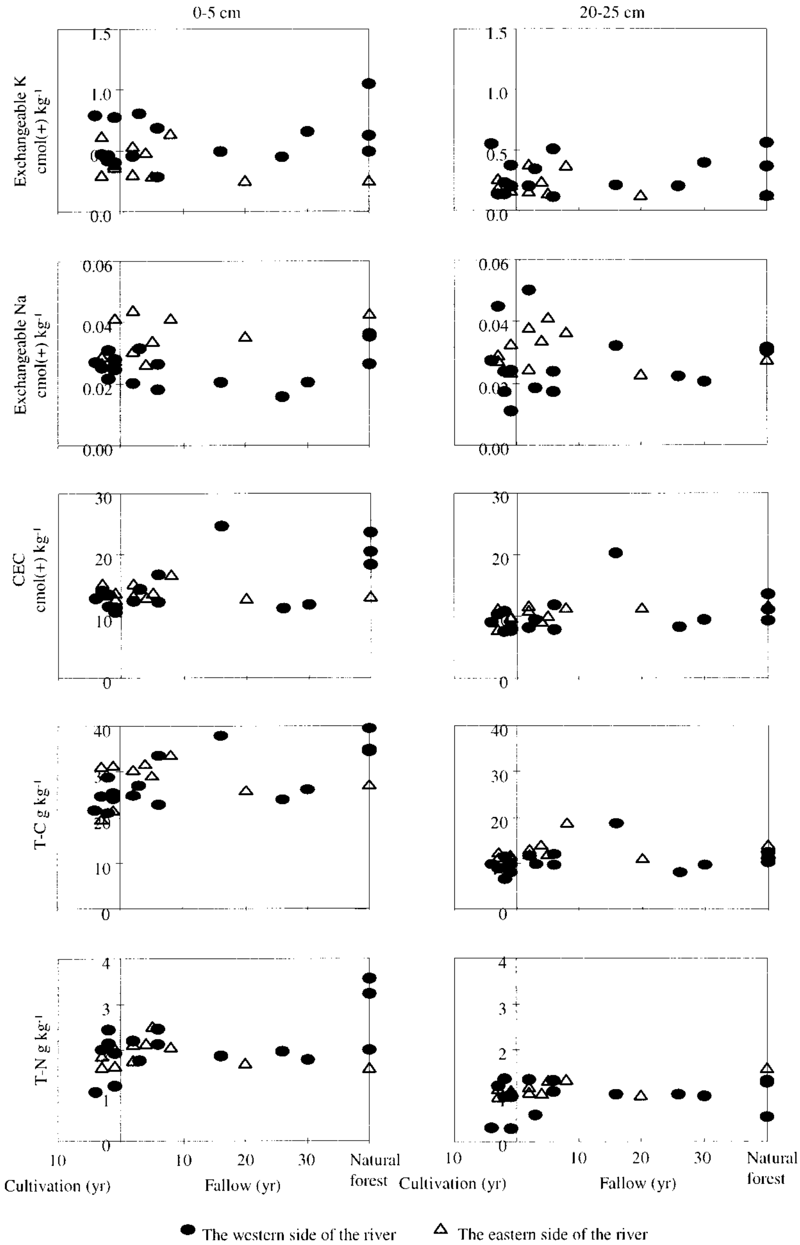

Fig. 2—Continued

al. 1985; Funakawa *et al*. 1997a; 1997b].

The study sites showed low CEC values throughout, irrespective of the high clay content (Table 4). Most of the soils of the study sites can be classified as soils with low activity clay [Uehara 1979]. Av-P content was moderately high under the condition of no fertilizer application by the farmers. On the eastern side, Av-P content showed a slightly higher value than on the western side. There was a significant correlation between the length of fallow period and the amount of T-C in surface soils within the first 10 years fallow (r=0.525, $p<0.05$), while natural forest showed a wide range of T-C value. Fallowing for longer than 10 years does not always contribute to the increase in T-C and T-N contents. T-C and T-N contents of strongly weathered soils may not be easily recovered during fallow period since the original level itself is very low. These values on the eastern side were slightly higher than those on the western side.

Organic matter dynamics under shifting cultivation system have been well analyzed [Funakawa *et al*. 1997a; 1997b; Burbacher *et al*. 1989; Nye and Greenland 1960; 1964], and most authors agree that organic matter and nutrient content in soil increase with longer bush or tree fallow. Roder *et al*. [1995] found, however, that the fallow length showed only a very weak association with soil organic matter. Lack of information on long-term land use history, including land use before present fallow, may cause this discrepancy. Our study suggests that farmers use shorter fallow periods for soils with higher fertility so that it is still difficult to draw definite conclusions about the relationship between soil fertility and fallow length.

IV–4 *Changes of Soil Chemical Properties during the Cropping Period*

Six sites, Fa30, Fa6 and C1 in TKW, and Fa26, Fa6 and C2 in LLW, were cultivated in 2000. The changes in soil chemical properties of these six sites during the cropping period are shown in Table 5.

The pH increased during the period from February to October with the changes in pH greater in the fields with a long fallow than in the fields continuously cropped. This difference can be clearly observed in TKW-C1 and TKW-Fa30. The former showed 0.4 units of difference in pH between February and October, while the latter showed a difference of 0.8 units. This might be due to the larger amount of aboveground biomass available for burning in the field with longer fallow. Kyuma *et al*. [1985] reported that pH increased immediately after burning and decreased immediately after sowing, and pH value after harvest was still higher than immediately after felling the trees. Our findings support this observation.

Exchangeable Al content at the depth of 0–5 cm and 20–25 cm decreased during experimental period except for the 20–25 cm layers at LLW-Fa6 and LLW-Fa26 and the 0–5 cm layer at TKW-C1. Exchangeable H did not show a consistent pattern. Exchangeable Ca and Mg increased except for LLW-C2 and LLW-Fa6. The value of base saturations (BS) in the surface soil increased in all of the study sites. Exchangeable K content was higher in July, and decreased thereafter. The similar change of exchangeable K was already reported

Table 5 Changes in Soil Chemical Properties of the Cultivated Fields during the Cropping Period in 2000

Sample	Depth		pH (H_2O)	pH (KCl)	EC	Exchangeable Cations Al	H	Ca	Mg	Na	K	CEC	BS	AvP	T-C	T-N
	cm				mS m^{-1}	cmol (+) kg^{-1}							%	mg kg^{-1}	g kg^{-1}	
TKW-Fa30	0 – 5	Feb.	5.08	3.88	3.86	1.50	0.62	0.47	0.64	0.02	0.66	11.9	15.1	14.3	26.0	1.8
		Jul.	5.69	4.10	2.81	0.55	0.39	1.97	1.28	0.01	1.00	12.4	34.5	10.2	33.0	1.9
		Oct.	6.05	4.53	2.79	0.16	0.24	2.87	1.79	0.01	0.87	12.5	44.2	25.4	40.4	2.3
	20–25	Feb.	4.89	3.79	1.98	4.39	0.74	0.06	0.08	0.02	0.40	9.5	5.8	2.8	9.5	1.0
		Jul.	4.80	3.82	1.03	3.80	0.52	0.16	0.09	0.02	0.38	7.5	8.6	3.6	8.4	0.8
		Oct.	5.36	4.02	1.66	2.82	0.62	0.39	0.33	0.02	0.58	11.4	11.6	3.7	15.2	1.2
TKW-Fa6	0 – 5	Feb.	6.11	5.33	6.01	0.03	0.00	7.24	1.94	0.03	0.68	12.3	80.2	5.6	22.7	2.1
		Jul.	6.47	5.58	5.45	0.00	0.10	9.01	2.47	0.01	1.25	14.4	88.3	17.2	27.2	2.2
		Oct.	6.92	5.97	5.62	0.00	0.03	10.63	2.54	0.01	0.92	14.7	96.0	25.5	29.4	2.5
	20–25	Feb.	5.78	4.51	1.82	0.03	0.10	4.16	1.20	0.02	0.50	7.9	74.5	2.6	9.5	1.1
		Jul.	6.02	4.72	2.13	0.00	0.13	4.39	1.28	0.02	0.46	9.3	65.9	3.6	10.8	1.1
		Oct.	6.28	4.73	1.43	0.00	0.13	3.97	1.13	0.02	0.61	8.9	64.0	6.6	11.0	1.1
TKW-C1	0 – 5	Feb.	5.20	3.98	3.78	1.12	0.66	0.55	0.55	0.02	0.77	10.8	17.6	13.6	25.4	1.9
		Jul.	5.54	4.01	3.30	1.03	0.51	1.45	0.87	0.01	1.00	11.4	29.3	14.2	27.2	1.8
		Oct.	5.60	4.16	1.73	1.51	0.42	0.91	0.51	0.01	0.72	9.7	22.2	11.9	25.5	1.8
	20–25	Feb.	4.92	3.84	2.04	3.10	0.26	0.09	0.08	0.01	0.37	8.1	6.9	3.2	9.6	1.0
		Jul.	4.86	3.84	1.45	3.48	0.58	0.20	0.13	0.01	0.35	8.0	8.8	4.6	11.9	1.0
		Oct.	5.19	4.03	1.51	3.08	0.60	0.15	0.08	0.01	0.36	8.6	6.9	3.4	14.7	1.2
LLW-Fa26	0 – 5	Feb.	5.32	4.11	3.23	0.67	0.54	2.38	1.35	0.02	0.44	11.4	36.9	10.5	24.0	2.0
		Jul.	5.71	4.26	4.64	0.12	0.35	3.24	1.62	0.01	0.69	11.2	49.7	15.2	25.8	1.9
		Oct.	6.04	4.75	2.63	0.00	0.14	5.33	2.40	0.01	0.26	12.7	62.8	8.9	28.6	2.1
	20–25	Feb.	5.06	3.75	1.50	2.99	0.36	0.38	0.39	0.02	0.20	8.2	12.0	2.3	8.0	1.0
		Jul	4.77	3.78	2.22	3.74	0.54	0.57	0.28	0.02	0.29	8.6	13.3	3.2	9.5	1.0
		Oct.	5.40	4.00	1.12	3.04	0.35	0.98	0.84	0.01	0.14	10.6	18.7	1.8	9.8	1.1
LLW-Fa6	0 – 5	Feb.	5.88	4.97	4.38	0.03	0.03	8.94	3.42	0.02	0.28	16.8	75.2	5.5	33.4	2.5
		Jul.	6.39	5.09	3.52	0.00	0.14	9.12	2.94	0.01	0.56	16.4	76.9	11.4	30.4	2.1
		Oct.	6.30	5.41	2.94	0.00	0.06	10.38	3.10	0.01	0.34	16.4	84.2	5.8	31.6	2.1
	20–25	Feb.	5.30	3.84	1.56	1.09	0.03	3.73	1.44	0.02	0.11	11.9	44.5	2.3	11.9	1.3
		Jul.	5.38	3.78	1.39	3.17	0.72	2.12	0.79	0.02	0.11	10.8	28.3	1.8	10.8	1.3
		Oct.	5.60	4.01	1.23	2.08	0.60	2.61	1.10	0.01	0.09	11.3	33.6	1.2	13.1	1.3
LLW-C2	0 – 5	Feb.	5.55	4.54	4.76	0.08	0.03	5.75	1.65	0.03	0.46	13.5	58.5	2.1	28.8	2.4
		Jul.	5.76	4.35	3.69	0.06	0.32	4.48	1.21	0.02	0.79	12.1	53.6	17.8	24.1	2.0
		Oct.	5.99	4.71	3.16	0.00	0.13	5.22	1.90	0.03	0.59	12.4	62.2	7.7	27.4	2.3
	20–25	Feb.	5.00	3.73	1.56	3.33	0.42	1.23	0.55	0.02	0.14	10.8	18.1	2.3	11.5	1.4
		Jul.	4.73	3.73	2.35	4.71	0.59	0.47	0.24	0.02	0.19	9.0	10.2	2.5	10.0	1.3
		Oct.	5.03	3.89	1.86	2.78	0.59	0.83	0.48	0.02	0.15	9.2	16.0	2.1	13.6	1.4

[Tulaphitak *et al*. 1985; Stromgaard 1984]. AvP showed an increase at the fallow fields of TKW and a peak in July at Fa6 and C2 of LLW. The amount of T-C of the surface soil slightly decreased at LLW-C2 and Fa6, and increased at the other sites. There was little change in T-N content, although it increased at the surface soil of TKW-Fa6 and Fa30. It is reported that soil temperature increased and N mineralization decreased with increase in the amount of burned biomass [Tanaka *et al*. 2001]. We found an increase in T-N which suggests that, at least, the sustainable amount of biomass was burned for N mineralization. The biomass of the fallow vegetation generally represents the major pool for calcium, magnesium and potassium [Andresse and Schelhaas 1987; Nye and Greenland 1960; 1964; Sanchez 1987]. The changes in nutrients are, therefore, affected by the amount of vegetation biomass. The nutrients mostly increased after burning and cropping in this study, although the changes of different kinds of nutrient during the cropping period varied from site to site.

These results suggest that the accumulation of nutrients from ash was higher than the loss of nutrients during cropping. However, the increase in soil nutrients in the three years continuously cropped field (LLW-C2) was smaller than that in single year cropped fields. This indicates that continuous cropping without fertilizer degrades soil fertility and exhausts soil nutrients finally.

V Significance of the Fallow Period

Nakano [1978] noted that the soil fertility had only just recovered after 5 years fallow for shifting cultivation fields in northern Thailand and Zinke *et al*. [1978] found that the recovery of nutrients in the soil after only 1 year of cropping had barely been achieved after 9–10 years of fallowing. Despite these fertility constrains, Tulaphitak *et al*. [1985] suggested that decline in soil fertility might not be the decisive factor motivating farmers to fallow their fields even after 2 years continuous cropping. In our study, most of the nutrients were more abundant after harvest than before planting, and the supply of nutrients from ash was higher than the loss for cropping. These results suggest that soil fertility recovery was not the only, or even the most important reason why farmers fallow fields.

Local farmers consider that the fallow period is short if it is less than 6 years. They believe that short-fallow fields have more weeds. They have to weed four times per crop in case of short-fallow, whereas only two weedings are needed in the case of long-fallow. Roder *et al*. [1994] reported that the weeding requirement increased from 1.9 to 3.9 times with the decrease in the fallow period from 38 to 5 years. Weed control is significant for sustaining rice yields. Kamada *et al*. [1987] reported that burning suppressed the germination of seeds of annual herbs or grasses and stimulated seed germination of woody species.

The biggest difference between short- and long-fallow can be found in vegetation recovery. The typical vegetation after short-fallow is herbaceous whereas woody species predominate in long-fallow, and there must be more weed seeds in short-fallow fields than in long-fallow fields. The intensity of the fire after short-fallow must be less than after long-fallow because of differences in the composition and volume of biomass. This results in more weeds for short-fallow. Therefore, we conclude that the significance of fallow period is to get a large amount of biomass to control the weeds by burning.

VI　A Sustainable Farming System for Short Fallow Fields

Population growth and enforcement of government regulations against clearing new fields in forest areas will inevitably force intensification of cropping on existing agricultural fields with a consequent reduction in the length of the fallow period. Are there any potential farming systems that can sustain production under such conditions? Based on the discussion in the previous sections, it can be concluded as follows: soils in the study area have reasonably high content of soil nutrients despite being on erosion-prone sloping land. Soil fertility status may not be fully restored even when the length of fallow is 10 years but the accumulated nutrients in the soil during fallow period are small compared with the nutrients supplied from the ash input when the biomass is burned so that soil nutrients were found not to be exhausted after a single year of cultivation. However, the density of weeds increases if the fallow period becomes shorter. Therefore, fallow plays an important role in weed control during the cropping period, whereas its function for recovering soil fertility is weak. Given this situation, what type of farming system might be sustainable?

As one promising system, we propose the introduction of paper mulberry (*Broussonetia papyrifera*) during fallow in the system. Paper mulberry is a shrubby tree that commonly appears as a pioneer species in swidden fields in Northern Laos. If left undisturbed the trees regenerate during the fallow period. Villagers have long harvested the inner bark of stems of mulberry trees grown in bush fallows for local processing into a coarse-textured parchment. Recent development of a domestic processing industry and the opening of export market channels have encouraged farmers to retain paper mulberry volunteers in their swidden fields and to begin experimenting with propagation and intercropping systems to intensify production of the cash crop in fallow fields [Fahrney *et al*. 1997]. Luang Phabang and Xayaburi are currently the center of paper mulberry production in Laos [Tajima 2000].

Okabayashi [2002] reported that the values of pH, exchangeable Ca and K, and AvP in soils increased with the length of the paper mulberry planting period. Although it is not yet clear whether the soil fertility improvement is directly related to the planting of paper mulberry or not, we think that growing paper mulberry trees does not cause significant nutrient loss. According to Kang [1997], the presence of woody species in the alley cropping production system contributed to (1) nutrient recycling, (2) reduction in soil nutrient leaching losses, (3) stimulation of higher soil faunal activities, (4) soil erosion control, (5) soil fertility improvement, and (6) sustained levels of crop production. We can expect the same effects by introducing paper mulberry planting to swidden agriculture. Moreover, we can expect it to generate a large amount of aboveground biomass even after short-fallow. According to our measurement in the study site, paper mulberry can yield 10 tons of biomass per hectare per year, while herbaceous vegetation yields 6 tons. Burning this large amount of biomass will increase fire intensity and suppress germination of weed seeds. Farmers can also obtain some income from selling the inner bark of paper mulberry. This economic incentive should help to spread of this agroforestry system easily. It is, therefore, necessary to widely study the applicability of this system both from agronomic and economic viewpoints.

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